Design of the grade separation of Gippsland Railway at Narre Warren Cranbourne Road

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SYNOPSIS

This paper discusses the design of the grade separation of the existing level crossing of the Gippsland Railway and Narre Warren Cranbourne Road in the rapidly growing outer Melbourne suburb of Narre Warren. The grade separation is achieved by lowering of the road gradeline to underpass the railway and duplicating the road. The aim of the design is to minimise the road lowering to attain a satisfactory vertical alignment for the grade separation such that required sight distances are achieved whilst maintaining the existing rail grade. This design aim was achieved by minimising the structural depth through adoption of a "through girder" type bridge constructed from prestressed concrete. The bridge was designed to be constructed alongside its final position and then jacked into place within a single weekend occupation of the rail tracks. The innovative solution discussed in this paper will maintain a safe operation for rail customers, without prolonged reduction in the level of service for both road and rail traffic and meet the objectives of the project.

1 INTRODUCTION

McConnell Dowell Construction Pty Ltd teamed with CW-DC Pty Ltd a wholly owned subsidiary of Connell Wagner Pty Ltd and submitted an innovative proposal to win a Design and Construct tender for the VicRoads Narre Warren Cranbourne Road duplication project.

This project involves the duplication of approximately 2400m and widening of a further 300m of Narre Warren Cranbourne Road including the grade separation of the Gippsland Railway. Narre Warren Cranbourne Road is a major arterial in an expanding suburban area and currently carries in excess of 20,000 vehicles per day on a two-lane carriageway. The grade separation is achieved by lowering the road gradeline to underpass the railway. The duplication will allow the introduction of wider traffic lanes to accommodate cyclists with increased safety and the pedestrian path layout will be improved and paths widened to also increase pedestrian safety. Fig. 1 shows the general site area with the works involved in this project.

The tender for the project was awarded on 16th April 2003 and the construction of the works is expected to be completed by end of 2004.

2 PROJECT DESCRIPTION

2.1 Road Design

The aim of the road design was to optimise the extent of road lowering required in order to minimise any problems with the presence of a high groundwater table at site and cost whilst providing satisfactory sight distances and taking account of rail infrastructure and utility services.

The rail track vertical alignment could not be changed due to the proximity of the nearby Narre Warren station and due to staging complications associated with the existing level crossing. Any change in the alignment would have incurred significant cost to modify the rail infrastructure as well as the station platform. The rail bridge is therefore being constructed to suit the present track alignment. Track occupations will be required for the construction of the bridge, and as these are expensive they needed to be kept to the minimum.

The construction of the bridge has to be undertaken within the busy road environment which exists in this thriving growth area. In addition, at this location the available road reserve is very narrow.

Within these constraints, the VicRoads’ horizontal alignment of the road provided at tender was moved towards to the west boundary of the railway tracks. In addition the median width at the bridge location was also reduced from VicRoads design. The objective of this was to allow a single span bridge to be constructed. This enabled the operation of the existing road to be maintained for traffic while constructing the entire bridge on the new road alignment adjacent to its final location, thereby eliminating the need for two track possessions as well as ensuring that all the foundation works for the bridge will not be affected by the existing overhead track gantries.

Initial geotechnical investigation at the site indicated that there is an unknown groundwater aquifer source with a high groundwater table only 1-2m below natural surface. It is therefore preferable to keep the road as high as possible to minimise ongoing problems caused through groundwater ingress into the pavements. Difficulties in providing access to properties as well as the extent of retaining walls have been reduced by minimising the road lowering required.

For these reasons, a “through girder” rail bridge was developed as the preferred option. With this bridge solution the effective bridge deck depth was reduced to 400mm. The road lowering had to also allow for ballast thickness of 300mm, sleeper thickness of 200mm and the minimum required headroom clearance of 5.4m.

Accordingly, a grade for the cutting of about 4% was achieved at this location, with which all the necessary sight distance requirements were met, except near the intersection with Princes Highway. At Princes Highway, VicRoads advised that, due to the existing conditions, the intersection need not satisfy standard V80 stopping sight distance requirements, but should be sufficient to provide a comfortable ride through the intersection and that drivers should not lose sight of a vehicle ahead of them.

Elsewhere, the alignment was also modified to minimise the need for services diversion in order to minimise costs and any delays in the construction of the works.

The road pavement crossfalls vary to suit the drainage proposed at any particular location, with crossfalls to a swale drain in the central median over large parts of the project. In the sag curve under the rail bridge the pavement will crossfall to the east due to the superelevation requirement and a piped system was needed to deliver run off to the west side where the pumpstation is provided.

The road cross section allows for 3 lanes in each carriageway under the bridge with provision for pedestrian and shared pathways. In order to minimise the bridge span and resultant impact on existing traffic on Narre Warren Cranbourne Road during staging operations the pedestrian and shared pathways do not pass under the main span. Instead they pass under separate approach structures. These are supported on the bridge deck at one end and by a spread footing at the other. The adoption of a spread footing minimised required occupations of the rail track for construction of piles and the requirements for deviation of existing Narre Warren Cranbourne Road traffic and level crossing to bypass the works.

2.2 Retaining Walls

The road lowering near the rail bridge will be up to 6m below existing surface and due to the narrow road reserve at this location retaining walls are required. These walls will be integrated in the design to contribute to the aesthetics of the precinct through wall face treatments and landscaping.

Typical retaining walls consisted of soil nails with shotcrete facing. These were adopted along a total length of 390m. These walls were designed using the Slope/W software. The soil nail wall immediately below the bridge was designed for the loads from the precast spread footings of the approach spans as well as the surcharge loads due to rail traffic. The soil nails assist in restraining the bridge piles for resisting train impact forces as described later in section 6.

Bored pile walls with shotcrete infills were adopted near the western abutment for a length of 45m to accommodate a pumpstation within the road reserve and provide room for diversion of a major water supply main around the bridge site. These walls were designed using the Wallop software.

2.3 Drainage Design

The objective of the drainage strategy is to design a cost effective environmentally sustainable storm water drainage system incorporating swale drains and wetlands as much as possible. This helps with the pretreatment for the road run off and also to reduce the extent of any piped drainage system. In addition to being economical, the grassed swale drains increase the water quality and provide the opportunity to improve the appearance of the road with appropriate landscaping. The swale will also include bio retention trenches for additional treatment where necessary.

The drainage system for the works takes account of the Hallam Main Drain, and also the other extensive existing drainage assets along the route including the existing Melbourne Water retarding basin and wetlands opposite Norfolk Drive and adjacent to Golf Links Road. The road level was set to allow overtopping over extents defined by Melbourne Water.

2.4 Pump Station

A pumping station is required for the sag point of the road where it underpasses the rail. The road geometry and crossfalls have been set such that runoffs from beyond the sag curve cannot enter the sag catchment in high return periods so as to optimise the pump station design. Moreover, storage in the pipe system and the outer lane has been taken into account in the sizing of the pumps and the pumpstation.

The pumpstation will be 3m in diameter, about 6m deep, and located immediately adjacent to the bored piled wall.

The pumpstation will have a back-up power supply and dual pumps so that the risk of flooding in unforeseen events is minimised. In addition, a low flow pump will be included for extremely low flow and seepage flows. The pump arrangement will be such that the two main pumps will cycle so that wear and tear between the two is evened out. Both pumps will operate in the design 10-year ARI event.

2.5 Hallam Main Drain Bridge

The duplication of Narre Warren Road meant that the existing bridge across the Hallam Main Drain needed to be duplicated as well. The tender document required that the cross section of the Hallam Main Drain crossing to match the existing to avoid any adverse effects on the flood levels in Hallam Main Drain. As such, pier positions for the new bridge were located in line with the existing piers and the soffit of the bridge deck were also maintained not lower than the existing bridge deck.

This resulted in a simply supported three-span bridge with the span ranging from 6m to 9.2m. A precast hollow core slab deck with an insitu overlay was adopted for the superstructure and the substructure comprised of driven piles and a crosshead.

2.6 Rail Bridge

During tender alternative schemes of jacking the entire bridge deck under the rail tracks so that the rail services would proceed without any interruption were considered. However these were not as economical as the bridge scheme. Therefore the major objective of the grade separation will be achieved by construction of a prestressed through girder bridge with a span of 32.8m on a skew to the road of about 30°. The through girder bridge will minimise the effective structural depth so as to reduce as much as possible the road lowering. The bridge will be supported by 1.5m diameter bored piles and the bore log information shows that Silurian Mudstone is expected at a depth of about 14m to form the founding material for these piles.

There will be a 5m span reinforced concrete through girder approach structure on either ends of the bridge to span over the shared and pedestrian pathways. This structure will span between the soil nailed retaining wall and the bridge crosshead in order to limit its span and depth. This also assisted in staging of the works.

The foundations for the approach structure consist of spread footings. Geotechnical investigation showed that bearing capacity of the in-situ material was too low to be able to carry the foundation load and therefore the soil beneath the foundation for a width of 3m and a depth of 2m will be replaced with cement treated crushed rock during the track occupation necessary to install the bridge.

The bridge is 9.4m wide and is designed for each track being simultaneously loaded with a 300-A-12 rail loading.

A refuge platform for each track on the bridge, hand railing and a walkway on the approach structure is provided for the maintenance personnel. A recess in the top of the girder is also allowed for the running of the services. Figures 2 & 3 shows the elevation and section of the bridge.

The remainder of the paper will address some of the unique features of the Rail Bridge.
- Design development of the bridge;
- Main Girder design;
- Crosshead design;
- Rail impact design; and
- Bearings

3 DESIGN DEVELOPMENT

A through girder bridge was chosen to reduce the extent of lowering Narre Warren Road. The longitudinal grade line was based on a minimum 5.4m headroom clearance, a structural depth of 400mm for the deck slab and a ballasted track with an average ballast depth of 300mm and 200mm of concrete sleepers.

The rail bridge had to span the lowered Narre Warren Cranbourne Road as well as the 3m wide shared pathway at either side of the road. At the tender design stage, a two-span bridge was selected with each span of 21.6m. With this proposal, a pier was located in the central median and had to be protected from impact by errant vehicles. To incorporate all these elements a 4.5m wide central median was required. The construction of the bridge also required two track occupations as the bridge was intended to be built in two halves with the transfer of road traffic onto the lowered north bound carriageway before the existing rail level crossing could be demolished and the eastern span for the south bound carriageway constructed.

By moving the final alignment of Narre Warren Road to the west and diverting the entire traffic to the east temporarily during construction, the bridge could be built in one track occupation leading to saving in construction time as well as cost. The design was therefore modified to a 32.8m single span bridge. This allowed reduction of the central median width to 2.8m and improved the road safety by eliminating the hazard of a pier in the median

For the main span length selected there was still a need to bridge across the pedestrian and shared pathway at either ends of the bridge. For this 5m span, precast twin through girders for each track were designed to span between the bridge crosshead and the soil nail retaining wall.

At tender stage, the design of the bridge was based on rails being directly fixed to the deck slab with resilient, insulated fastenings instead of ballasted track. The advantage of "direct fix" track is that the effective structural depth allowance for the railtrack is 500mm less than the requirement for ballasted track.

However, "direct fix" track has the disadvantage of requiring increased accuracy in the positioning of the bridge deck construction and also not being as accommodating of differential vertical movement between the bridge deck and the bridge approaches. In addition the track maintenance contractor raised concerns at the detailed design stage about the maintenance of the "direct fix" track and the design was modified to include a ballasted deck as mentioned earlier. This resulted in the road gradeline being lowered to account for the ballast depth and sleeper thickness. To minimise lowering of the road, a rubber ballast mat was introduced to the deck. This produced two improvements to the design. They are:

- Reduction in the depth of ballast by 100mm;
- Provided a separation/insulation layer to prevent stray current corrosion emanating from the electrical rail system.

There is also a third advantage in that the introduction of the mat will reduce dynamic effects on the bridge and as a consequence, the impact factor used in the design could be lowered. This benefit however was not taken up in the design as it could not be quantified with certainty.

The existing track alignment imposed a constraint in the design of the bridge. Due to the proximity of Narre Warren Station, any realignment of the track will incur large costs and as such no modification to the track alignment was considered. Consequently with the through girder bridge option, the girder depth and position had to be clear of the train clearance envelope shown in Figure 3 which included allowance for cant, dynamic sway, maintenance etc. This envelope imposed a significant impact for the central girder in terms of its width and depth. As for the edge girders only the depth was governed by the train clearance envelope but the width was determined merely by the detailing requirements of the reinforcement and prestressing cables.

It was possible to deepen the girders, especially the central girder, by introducing a down stand, but this option was not preferred for two reasons. They are:

- the road gradeline would have to be lowered even further; and
- bridge construction would be more difficult with the down stand.

As a result a flat soffit was adopted and Figure 3 shows the section sizes adopted for the girders.

This bridge will be constructed within a very busy rail corridor. As such, negotiations were undertaken with the principal operator of the tracks National Express, operator of M<Trains and V/Line passengers and Freight Australia which operates freight services on the tracks, many of which occur late at night. The only practical track occupations were available between the last train on Friday to first train on Monday.

An innovative solution was developed to construct the bridge within a single weekend occupation. The intended construction method for the cost effective bridge option is to locate the piles supporting the bridge at least 4.5m away from the centre line of tracks such that installation of piles can be done with out the need for track occupation. The 1.5m diameter piles will be extended right up to the soffit of the crosshead to serve as piers. A pile cap will also be introduced to allow for the fixing of the permanent bearings after completion of launching. This also allows for jacking of the bridge should there be a need in the future to replace bearings.

The bridge girders will be monolithically cast with the crossheads on a ground beam at the north side of the existing rail tracks. The ground beams will be fitted on the top surface with stainless steel plate and rubber pads and guide beams at the sides of the beams to enable the launching operation to its correct alignment. Subsequently the bridge will be launched into its final position by fitting a launching nose on the south face of the crosshead and jacking using the northern piles as thrust blocks.

The crosshead is supported by pot bearings, which in turn sits on the pilecap. Longitudinally fixed bearing are located on the west piles as the height of piles above the ground level is lower here and guided, and free bearings are located on the east piles. The longitudinal movement due to creep, shrinkage and temperature are taken up at the end of the approach structure.

4 MAIN GIRDER DESIGN

The design of the superstructure was based on a two-dimensional grillage model developed using the ACES software. From this model, respective design actions were obtained to design the individual girders.

The chosen girder sizes were able to satisfy the Serviceability Limit State (SLS) requirements for the design actions derived from the model but could not meet the flexural requirement at Ultimate Limit State (ULS) as a singly reinforced/prestressed member. This is mainly due to the fact that girder dimensions within the critical compression zone was constrained by the train clearance envelope. The design then pursued a doubly reinforced design at Ultimate Limit State. Even then, if only 400 MPa strength was used for the reinforcement as per the current AustRoads Bridge Design Code (ABDC) requirements, it will lead to a significant number of compression reinforcements to satisfy the flexural strength at Ultimate Limit State. Due to the width limitations of the girder increasing the reinforcement numbers meant that they have to be located at much lower down from the extreme compression fibre, and as a result these reinforcements were ineffective.

VicRoads policy was to design the reinforcement based on 400 MPa strength as per ABDC even though 500 MPa strength reinforcement is being manufactured exclusively. VicRoads imposed this limitation mainly due to concerns of cracking in the member at Serviceability Limit State. In order to address this concern, the draft bridge design code AS5100 requires that the design is done to Ultimate Limit State and then a check carried out on the crack width requirements at Serviceability Limit State.

As the bridge is a single span the use of reinforcement in this case was only for the purpose of resisting compression. The reinforcements will not be subject to any tension for any load case. Therefore, it was felt that VicRoads imposed limitations may not necessarily be applicable for the design of this bridge.

A detailed review of the draft bridge design code also confirmed that no specific requirements needed to be satisfied in the case of reinforcement when used in compression with the design provisions for compression reinforcement appearing exactly the same as the current ABDC. This approach was discussed with VicRoads and upon their agreement the design was carried out by using compression reinforcement with strength of 500 MPa. The design for shear and torsion in the girder was based on a 400 MPa strength reinforcement.

The design of all the other members was based on a singly reinforced section at ULS and the design was accordingly based on reinforcement strength of 400 MPa.

5 CROSSHEAD DESIGN

The design of the crosshead had to be undertaken for the various construction stages. They are:

- Construction of the crosshead and after supporting the crosshead on the temporary launch PTFE coated elastomeric pads. Crosshead is designed for its self weight at Ultimate Limit State as a reinforced concrete member supported at rubber pads located at about 8m apart rather than the final design span of 14.5m.

- Casting of the bridge superstructure and after prestressing the through girders. Crosshead is designed at Ultimate Limit State as reinforced concrete member for the selfweight of the bridge with supports as mentioned above.

- After stressing two cables of the crosshead. The stress check at Serviceability Limit State and flexural check at Ultimate Limit State is carried out as a prestressed member for the support conditions as stated above. All the four cables in the crosshead could not be stressed at this stage as it will exceed the allowable tensile stress for the temporary support conditions.

- During the launching of the crosshead from the ground beam to its final position on top of the piles. During the launch, support conditions vary and the crosshead has been checked as reinforced concrete member for the bridge self weight together with the super imposed dead loads at Ultimate Limit State for the various critical conditions.

- After stressing the two remaining cables in the crosshead. Both the stress check and flexural check is carried out for the selfweight of the bridge and superimposed dead load as a prestressed member based on its final support conditions, which has a span of 14.9m.

- After completion of the construction. The crosshead was designed as a prestressed member from the design actions obtained from the two dimensional grillage model in its final condition when the crosshead is supported on the permanent bearing located on the pilecaps.

6 RAIL IMPACT

The original design concept was based on providing guard rails to protect the structure from an errant train impacting the girders. During the detailed design phase when an independent review of the rail safety was undertaken, concern was raised that this approach may not meet the necessary safety standards. As such in the final design the guard rails were removed and the superstructure was designed to resist the impact load from derailed trains.
The current bridge edition of ABDC provides guidance in terms of loading to be assumed due to rail impact on bridge piers but no similar loading guidelines were available for the design of superstructure for rail impact. As such, in the design, a conservative approach was taken and the same impact load as for the piers has been considered in the design of the superstructure.

For the design of the girder impact loads as given in the ABDC was used at the ends of the bridge and to about 2.5m into the bridge. Beyond this distance, the same load is unlikely to be realised for a train of about 10m in length due to the proximity of the adjacent girders. Consequently, the impact force along the girder was correspondingly reduced to account for the possible train impact angle. In the design, the train impact was assumed to act at the top of the girder with a contact length on the girder of 2.4m and a further 45 degree dispersion for the load was also assumed vertically. The deck slab was also designed for the out of balance moment from the eccentric derailed train.

In addition to considering the impact loads, a load case for a 300-A-12 train with the derailed train positioned as close as possible and parallel to the girders was considered in the design of the girders.

The design of piles and crossheads was done by developing a two-dimensional frame model comprising of the deck as a single longitudinal member and the two crossheads as transverse members with appropriate restraint condition provided by the bearings in SPACEGASS. The train impact loads were applied at each end of the girders of the bridge to determine the loads for the design of piles and the design actions for the crossheads.

A single pile was subsequently modeled in SPACEGASS as a series of 1m long members for the whole length of the pile. At these member nodes below the lowered Narre Warren Cranbourne Road restraints were applied by way of springs to model the support provided by the soil. Due to the large impact loads, soil nails were introduced into the pile at the New Jersey barrier level to reduce the pile bending moment. The New Jersey barrier is strengthened locally around the piles to ensure load spread to the soil nails anchoring the piles. The same model was also used to check the design action arising from the launching of the bridge especially for the north piles.

7 BEARINGS

An interesting feature of the proposed launching operation is the use of permanent pot bearings for the launching operation. As such the top plate of the permanent bearing will be cast into the crosshead flush with the soffit. This would require the orientation of the top bearing plate for the guided and free bearings in the direction of the launching. However in the final condition these bearings will have to be oriented in the longitudinal direction of the bridge which is different to the launching direction. Hence the cast plates within the crosshead need to have the flexibility to be rotated after the launch. This will be achieved by fixing the top plates with a stainless steel surface temporarily with ferrules and locating the final anchor bolts within enlarged dowel holes, which will only be grouted after rotating the plates on completion of the launch. In addition for the launching operation a temporary launch plate with the upper surface lined with stainless steel will be fixed on top of the actual bearing pot to permit the sliding of the crosshead. The rubber pads will be inserted between the two stainless steel surface during the launching operation of the crosshead.

8 CONCLUSIONS

An effective and innovative solution for the grade separation of the Gippsland Railway has been achieved by staging the works without any prolonged reduction in the level of service and by minimising or eliminating effects on the existing rail assets.